The 10th Anniversary Kaufman Memorial Symposium
Honoring the vibrant, inspirational life of Yoram Kaufman
and his significant scientific accomplishments

# Estimating Biomass Burning Smoke Plume Injection Height using CALIOP, MODIS and the NASA Langley Trajectory Model


**Amber J. Soja**

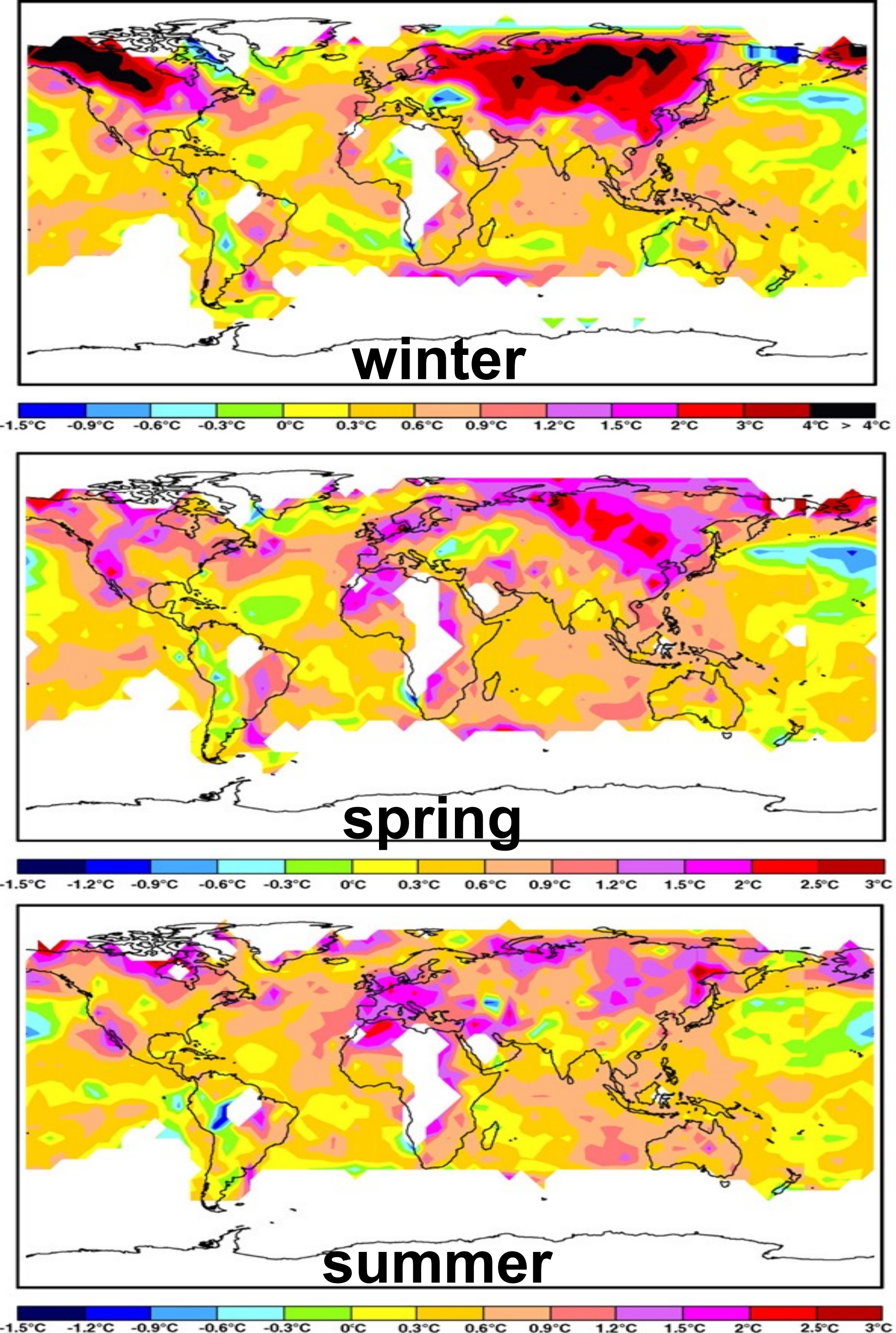
Hyun Deok Choi, Duncan Fairlie, George Pouliot, Jason Tackett, Roman Kowch, Mark Vaughan, Dave Winker, and Charles Trepte


**Photo courtesy of Brian Stocks**

NIA
NATIONAL INSTITUTE OF AEROSPACE

# Outline:

- Brief introduction of the driving forces of fire and smoke plume injection height
- Estimating Plume injection
    - Methodology
        - CALIOP, NOAA HMS, LaTM and MODIS
- Plume injection height result possibilities
    - Attribution of 1 plume to numerous fires
    - Diurnal cycle of plume injection height from the perspective of 1 fire (Tripod)
- Comparison of CALIOP-derived plume injection height to MISR data and CMAQ model




**Mean seasonal temperature change.**

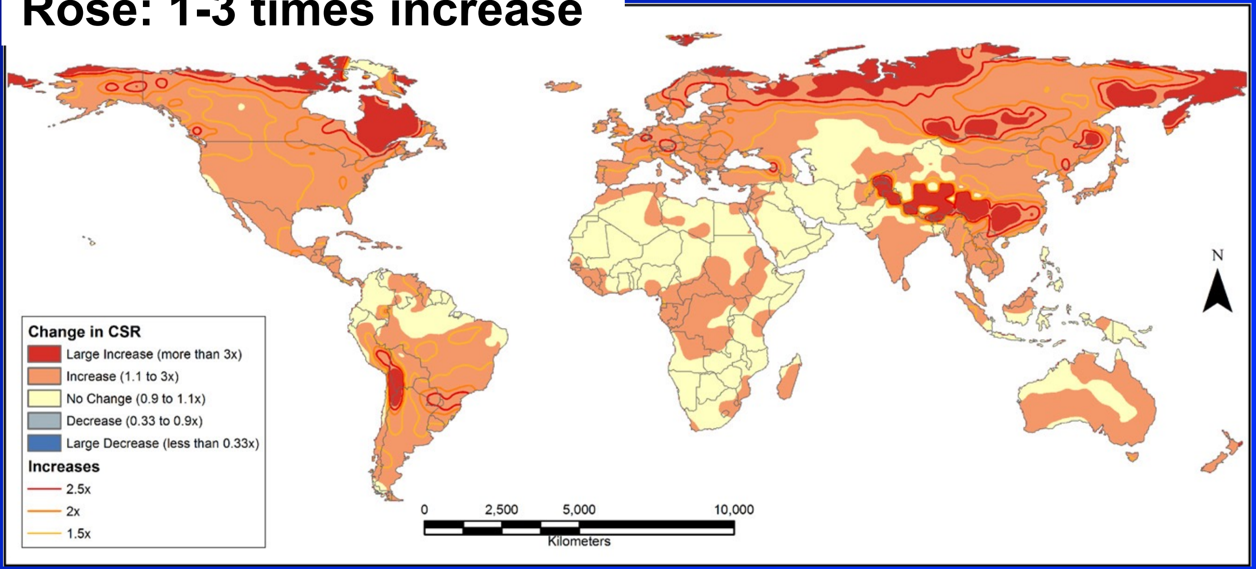
**Temperatures are increasing, particularly in the Northern Hemisphere winter and spring,**
**which leads to**
**longer growing seasons,**
**increased potential evapotranspiration and extreme fire weather.**

## It is time to get fire feedbacks integrated.

[Groisman et al., 2007; Jones and Moberg, 2003, updated]

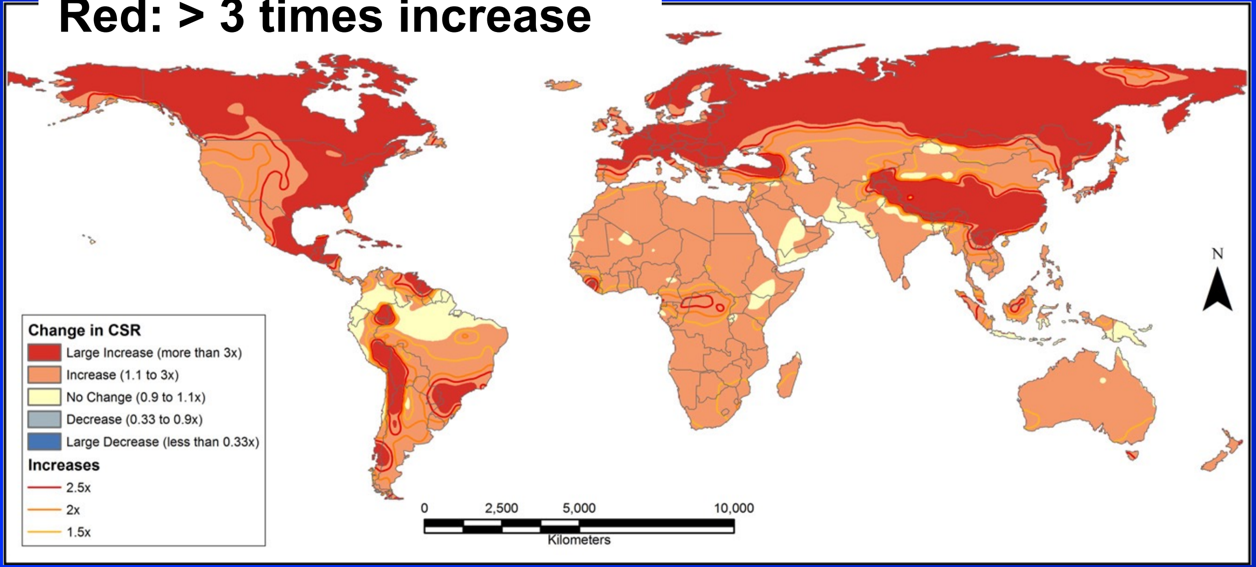
# Predicted Cumulative Fire Severity Rating

Rose: 1-3 times increase




Anomalies for 2041–2050, relative to 1971–2000 base period.

Red: > 3 times increase

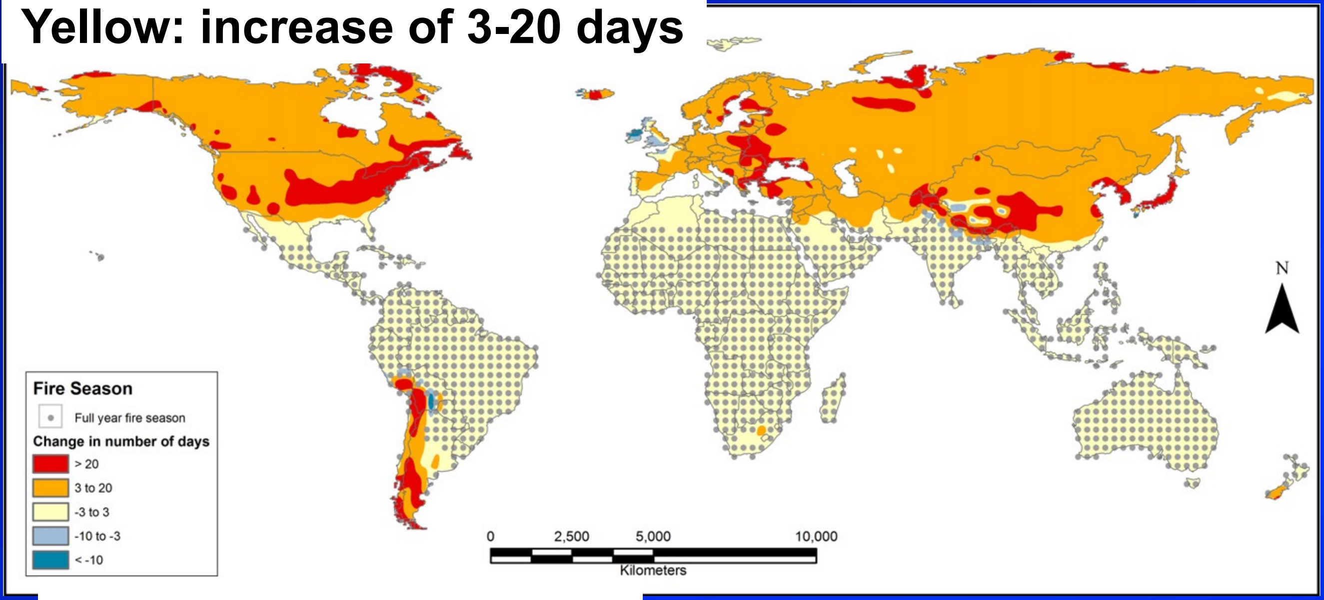



Anomalies for 2091–2100, relative to 1971–2000 base period.

Flannigan et al., 2013 Modeled based on French IPSL-CM4 A2 scenario

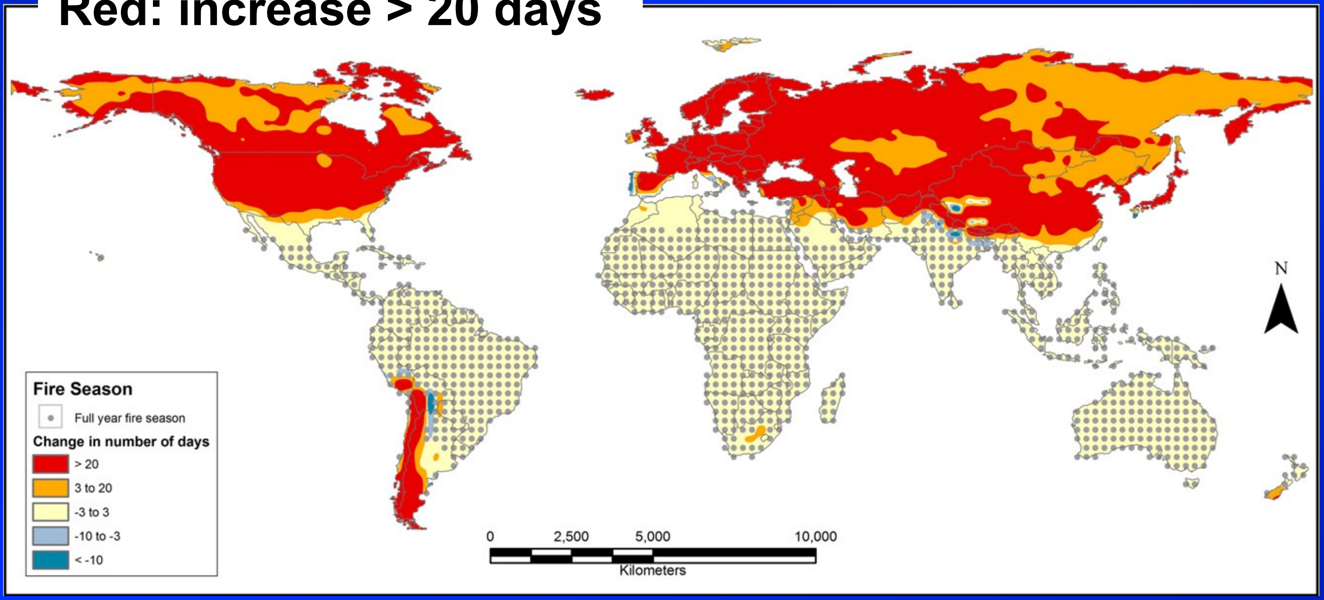
# Predicted Fire Season Length

Yellow: increase of 3-20 days




Anomaly for 2041–2050, relative to 1971–2000 base period.

Red: increase > 20 days




Anomaly for 2091–2100 relative to 1971–2000 base period.

Flannigan et al., 2013 Modeled based on Hadley CM3 B1 scenario

# If we don't get injection height correct, the transport of pollutants will be incorrectly modeled and tracked.

## Climate Feedbacks

* Smoke alters the Earth's radiation balance and feeds back to climate systems [e.g., patterns of precipitation (cloud condensation nuclei), change in Earths reflectance - albedo (vegetation change, clouds, black carbon on snow and ice].

## Air Quality

* A mis-informed public (air quality reports), which could adversely affect human health;

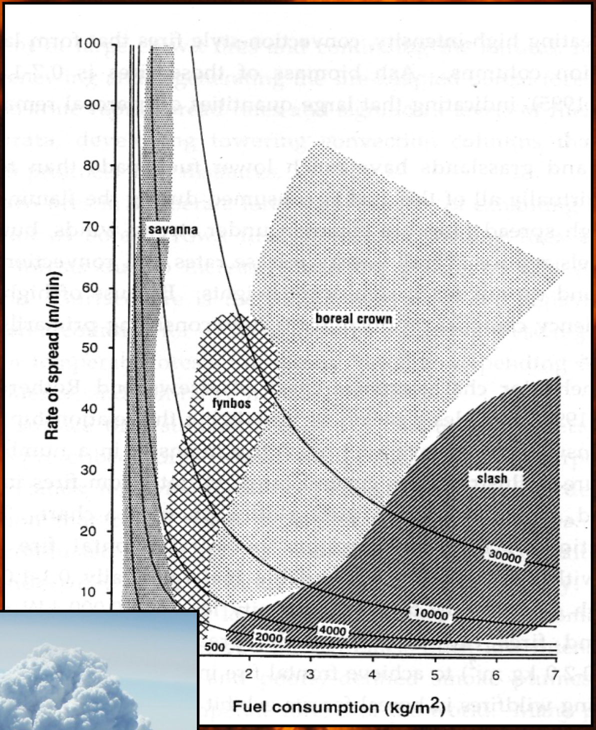
* In the U.S., inability to quickly and accurately assess the Exceptional Events Rule (72 FR 13560, March 22, 2007).

# Fire Intensity-Energy Release-Plume Height

- Combine rate of spread/fuel consumption/heat of combustion to determine fire intensity (I=HWR) = resistance to control

- Savanna Fires:
  - 10-12 t/ha
  - 500-10,000 kW/m
  - Lower convection columns

- Boreal/Temperate Forest Fires:
  - 25-50 t/ha
  - 100-100,000 kW/m
  - > fuel consumption & intensity
  - Towering convection columns reaching UTLS




A typical high-intensity boreal crown fire convection column viewed from an altitude of ~10 km *(photo courtesy Mr. Todo, JAL)*

**Driving force:**

**Fire Weather and Fuel**

# Fire Regimes Vary Widely: Fuel & conditions; time of day

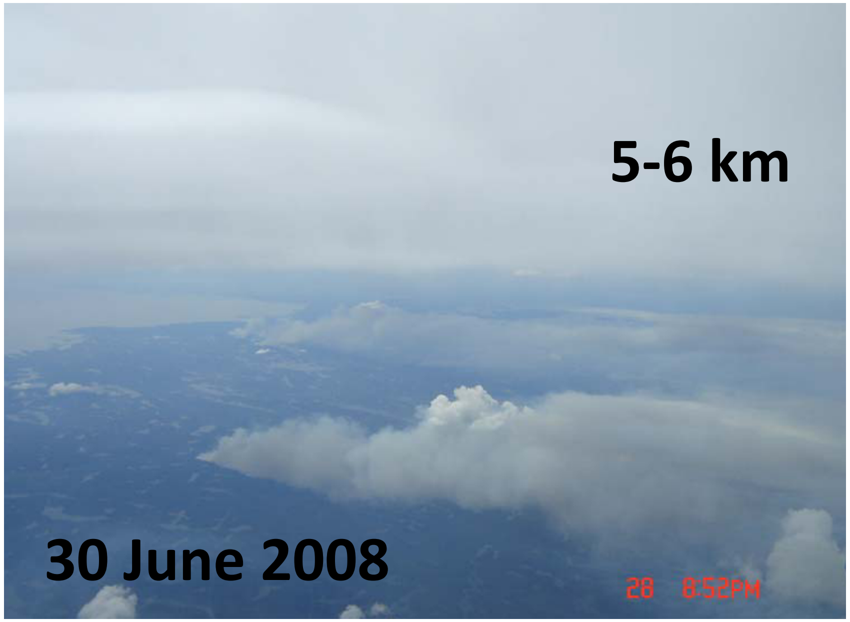

What burns and how dry are the fuels does matter.

** Peak <u>late afternoon</u> when the fuels are most available:

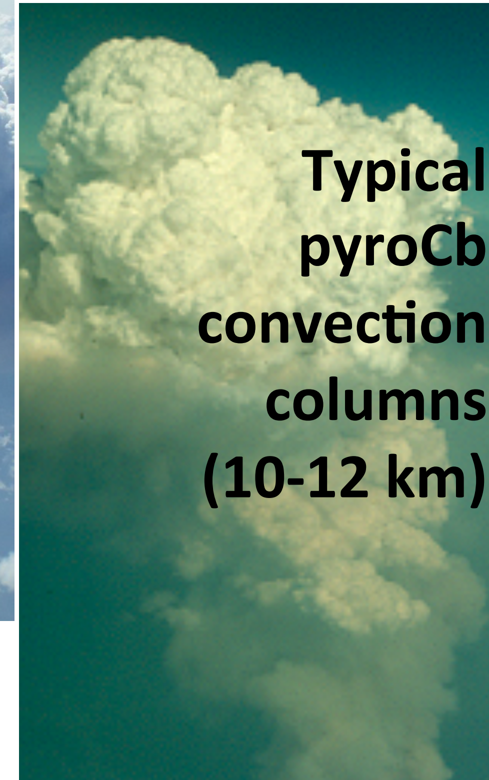
Hot, Dry,
Low
Relative
Humidity

Fires
lay down
at night

Photos:
Stocks and
Soja




ARCTAS: Photos courtesy P3 group





Air and smoke travel faster at higher altitudes

Climate → Weather → Available Fuel → Injection height


# History: Plume height modeling

*Based on the pioneering work of G.A. Briggs [1969; 1971] and verified with limited field data [Clements et al., 2007].*

*We have an increasing number of ground-based lidar and aircraft verification measures.*

*There are currently 2 satellites that can provide the statistics necessary to understand and verify plume height.*

I. *MISR - Multi-angle Imaging SpectroRadiometer*

II. *CALIPSO - Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation*

*CALIPSO*

** Increased capability of detecting optically thin smoke layers at a finer vertical resolution;*

** Able to identify plume heights from extensive smoke fields;*

** Paired with back trajectories, smoke plume identification are temporally random, representing the entire temporal range of fire plumes.*

*MISR*

** needs abrupt well-defined columns - relies on multi-view angles to estimate the stereo height of distinct features;*

** substantially larger swath width than CALIPSO which results in a greater opportunity to capture smoke plumes [Kahn et al., 2007]; &*

** morning overpasses do not capture the natural temporal fire pattern*

| Sensor (spacecraft) | Product | Spatial Resolution | Satellite Overpass | Temporal Availability |
|---|---|---|---|---|
| MISR (Terra) | AOD, aerosol plume height | 1.1 km horizontal x 500 m vertical | 10:30 a.m. | ~ Once every 7 days |
| CALIOP (CALIPSO) | extinction profile | 100 m diameter x 30 m vertical | 1:40 p.m. | Once every 16 days |

# Methodology


- Coincidence in CALIPSO tracks & NOAA Hazard Mapping System (HMS) smoke plume data;
- LaRC trajectory model (backwards);
- Coincidence with MODIS fire detection.

**All in 3-dimensional space and time**

# Each CALIOP air parcel is associated with the following related parameters:

<u>Fire</u>

Number of active Fire Detections (MODIS Terra and Aqua)

Fire Radiative Power

<u>Land</u>

IGBP vegetation 1km MODIS

Elevation

<u>Langley Trajectory Model (LaTM)</u>

Air parcel counts, mean range

<u>Meteorological</u>

Relative Humidity (2m, 10m)

Temperature (2m, 10m)

Wind speed and direction

Precipitation

Fire weather

Time of day

Planetary Boundary Layer

Stable Layer

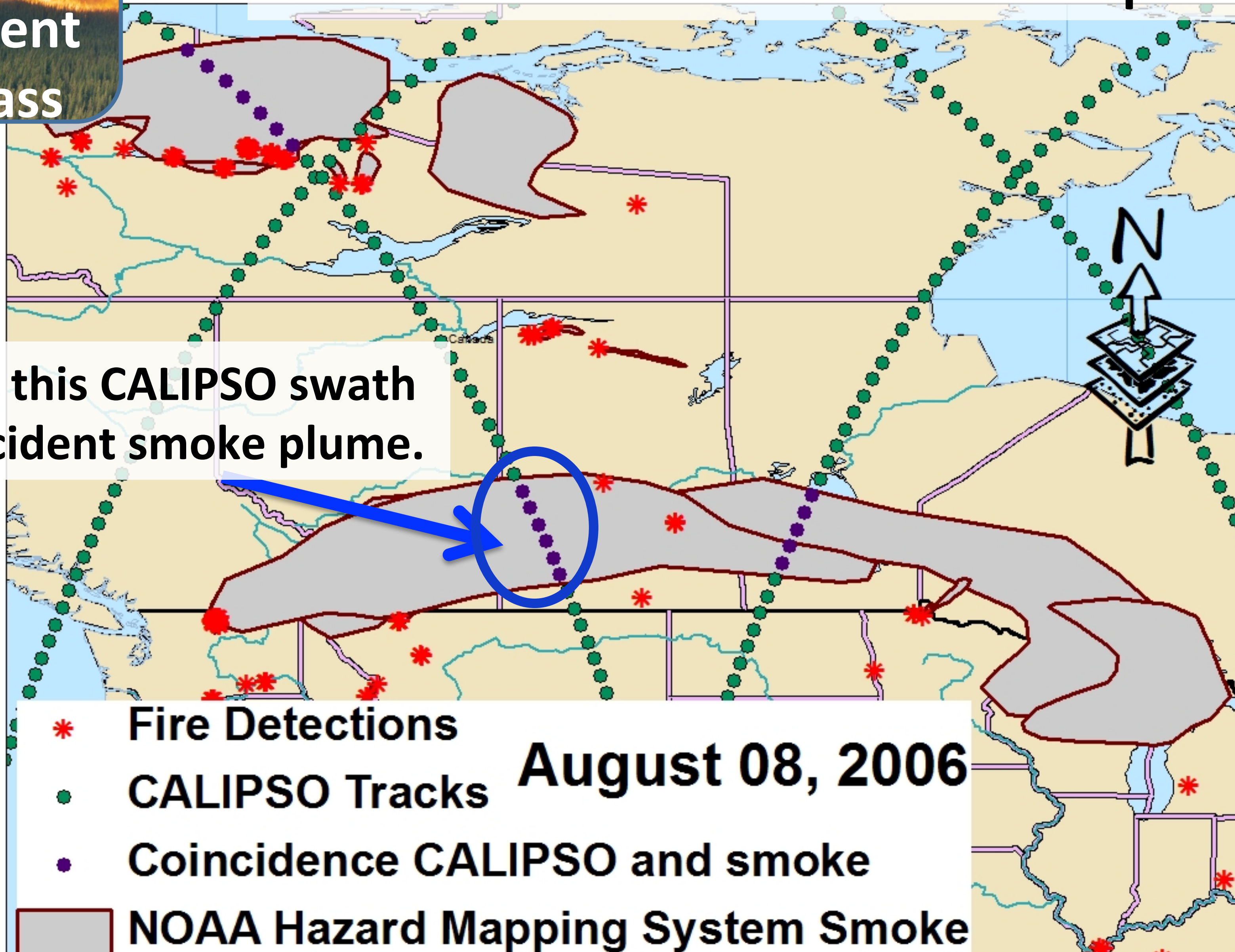
<u>Location</u>

Latitude/longitude
fire location and plume

Fire name

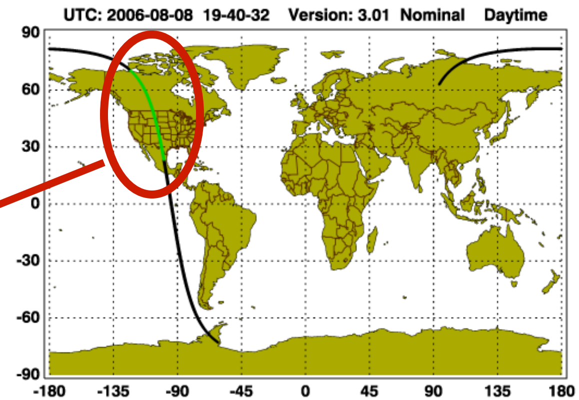
# Plume and CALIPSO Coincident Overpass

## Coincident NOAA HMS smoke plume, and CALIPSO overpass.

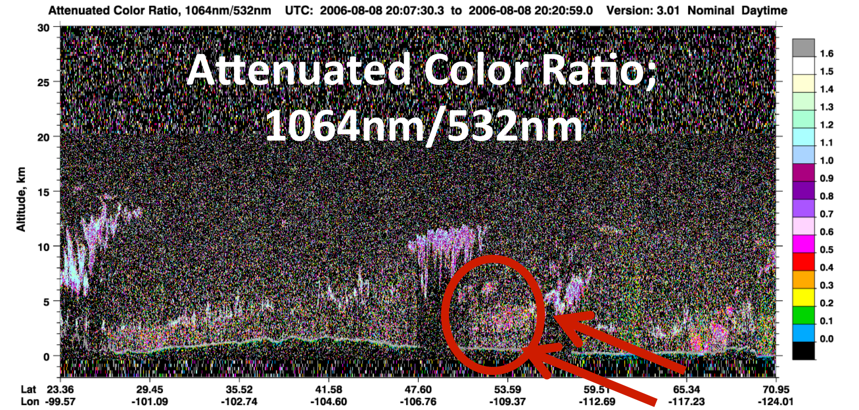



**Focus on this CALIPSO swath and coincident smoke plume.**

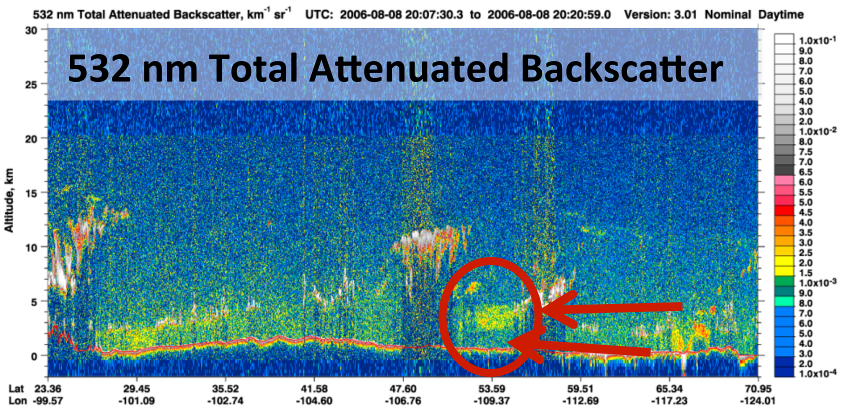

# CALIPSO Curtains 08 Aug 2006 (v3)



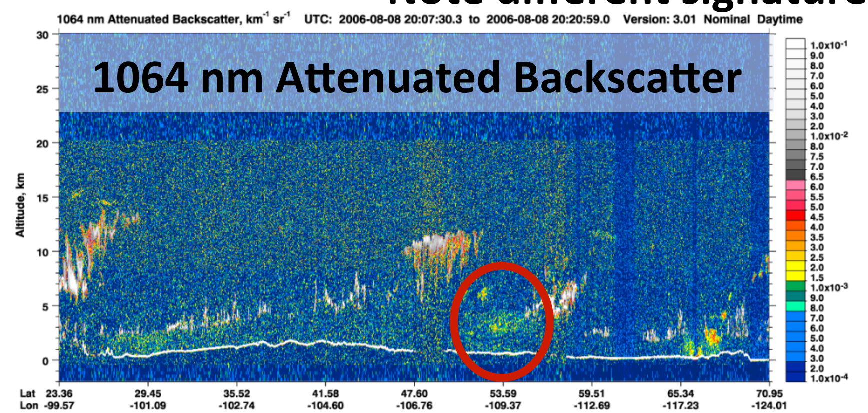

Swath from south to north

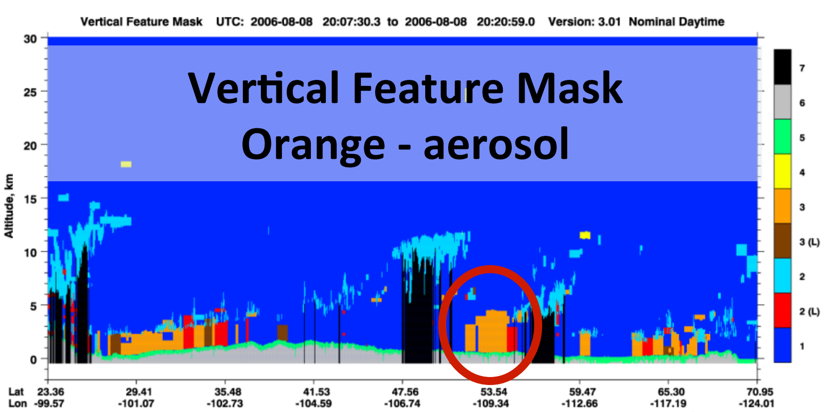


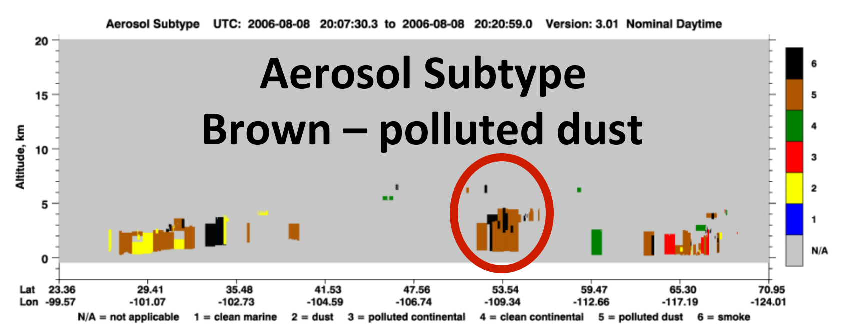

20:07 to 20:20

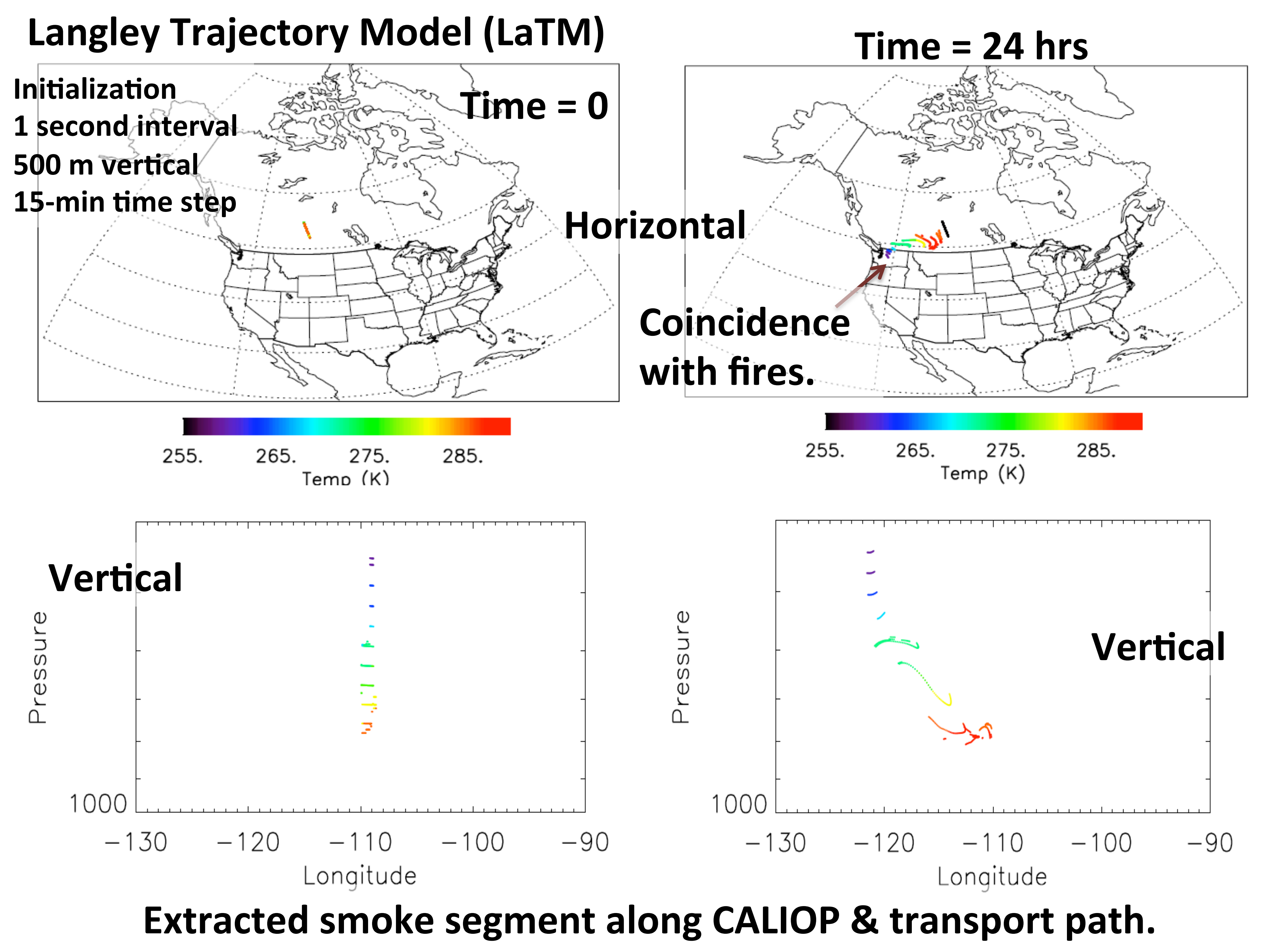



Note different signature



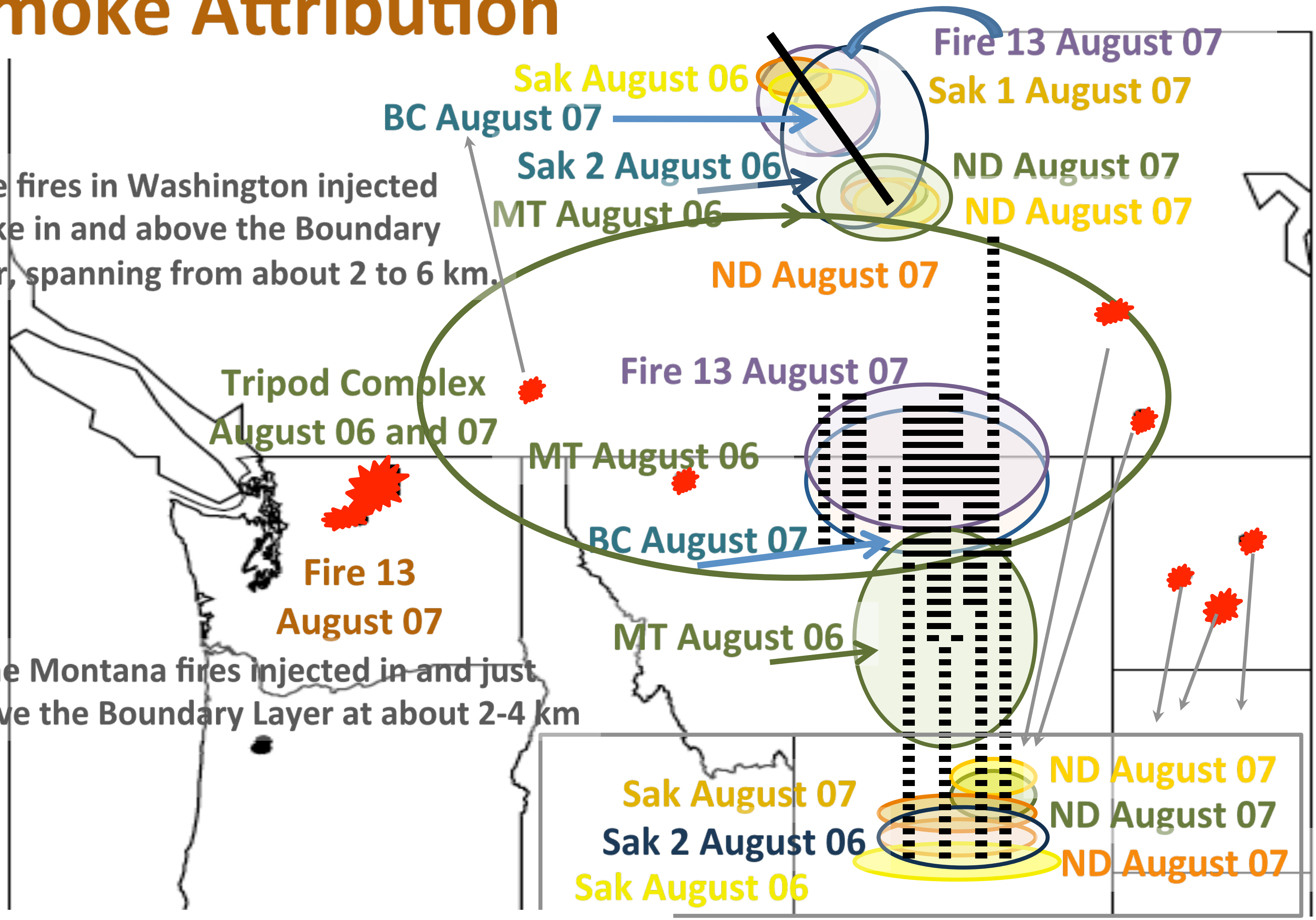

Langley Trajectory Model (LaTM)
Initialization
1 second interval
500 m vertical
15-min time step
Time = 0
Time = 24 hrs
Horizontal
Coincidence with fires.
255.
265.
275.
285.
Temp (K)
Vertical
Pressure
1000
−130
−120
−110
−100
−90
Longitude
Extracted smoke segment along CALIOP & transport path.

# Smoke Attribution

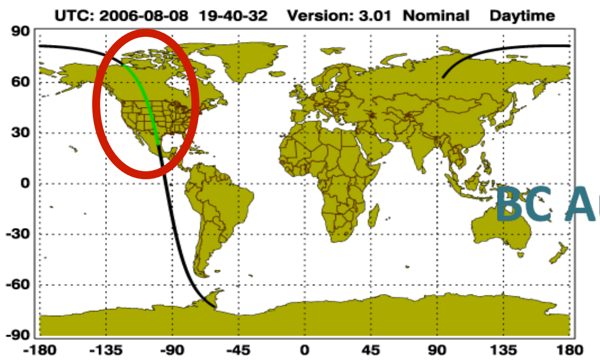
* The fires in Washington injected smoke in and above the Boundary Layer, spanning from about 2 to 6 km.

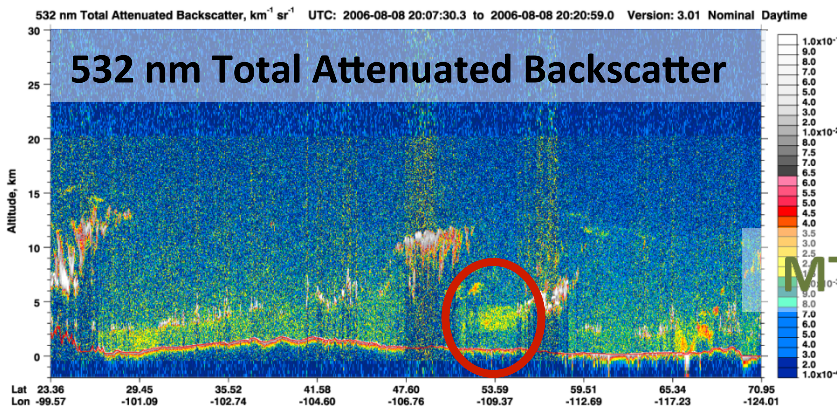
* The Montana fires injected in and just above the Boundary Layer at about 2-4 km

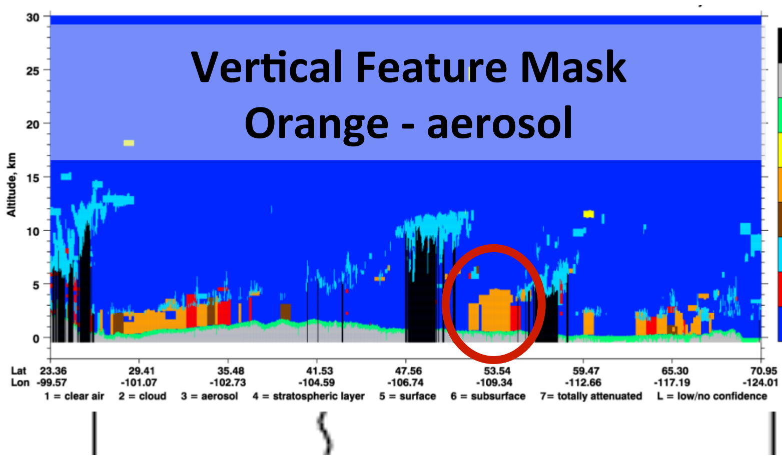
* All Saskatchewan and North Dakota fires injected in the Boundary Layer at around 1 km

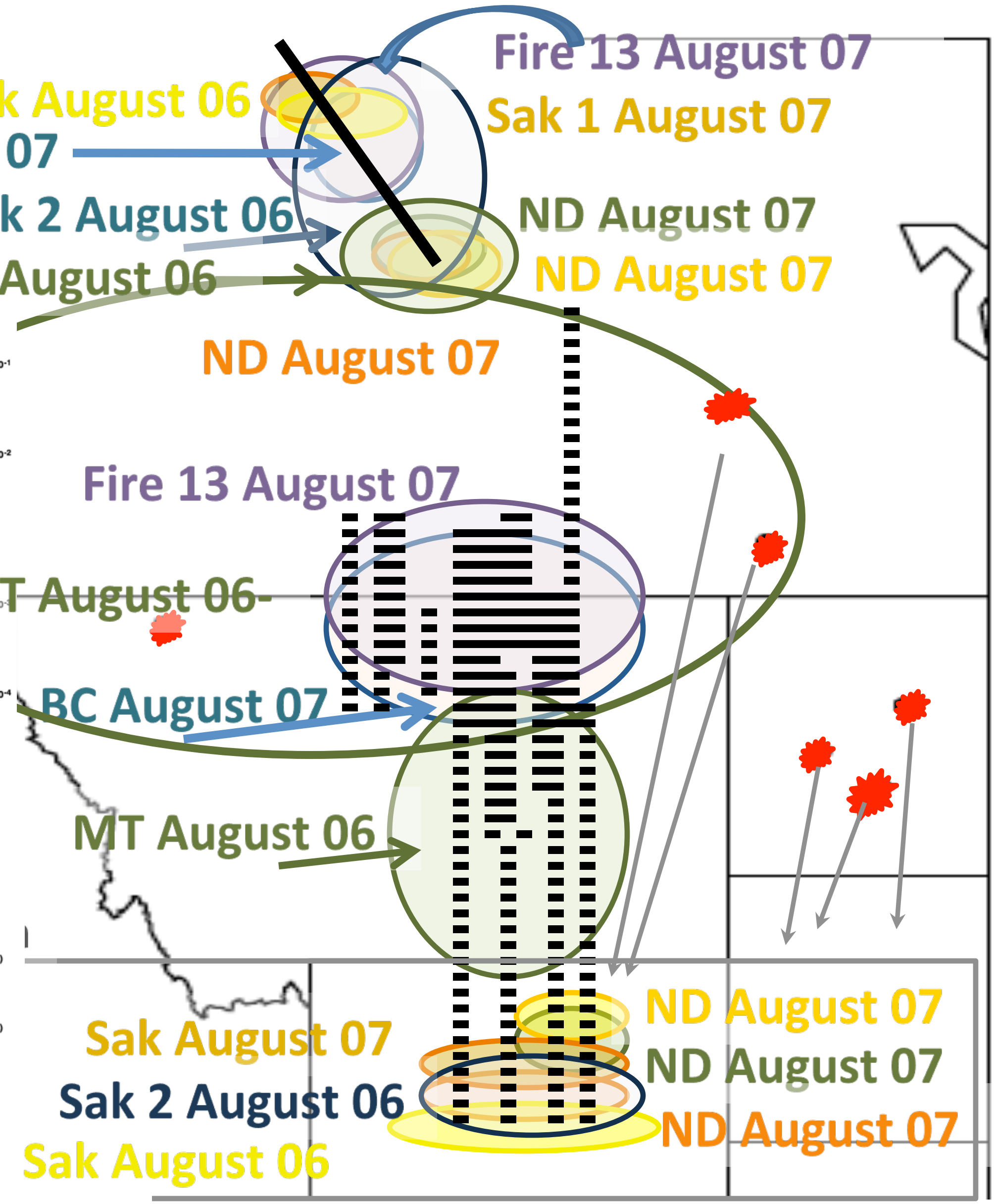



CALIOP Vertical Signal
August 08 2006



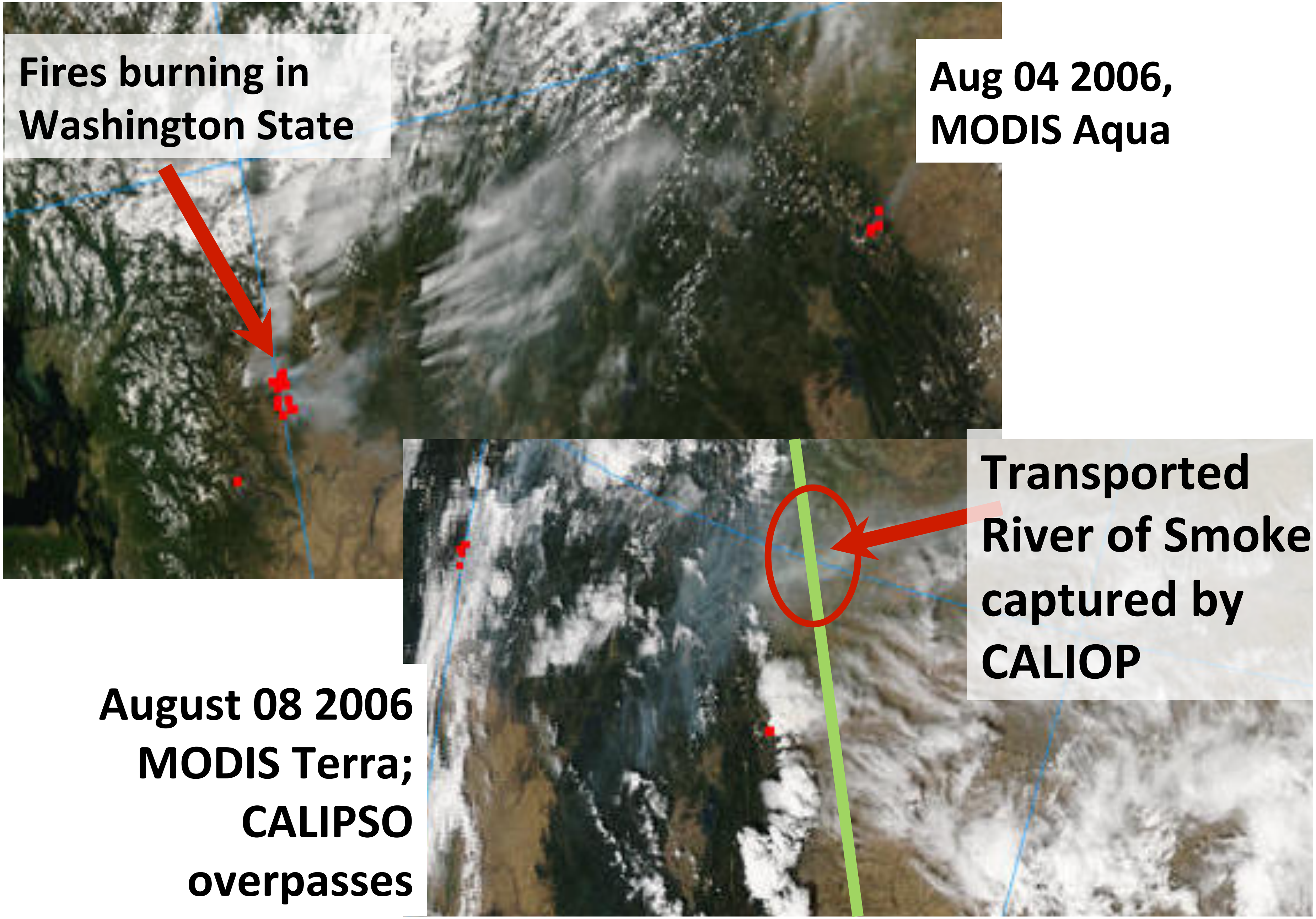




* All Saskatchewan and North Dakota fires injected in the Boundary Layer at around 1 km

CALIOP Vertical Signal
August 08 2006

# A River of Smoke



This plume can be attributed to 9 separate fires, burning on different days (12 fire-event-days):

Washington - large fire

- August 6th (~ 3400 m);
- August 7th (mean 3300 m, range 1900 – 6300 m);

Washington - medium-sized fire

- August 7th (range 2200 – 4400 m)

British Columbia

- August 7th about 3400 m

Montana fires – 2 of them

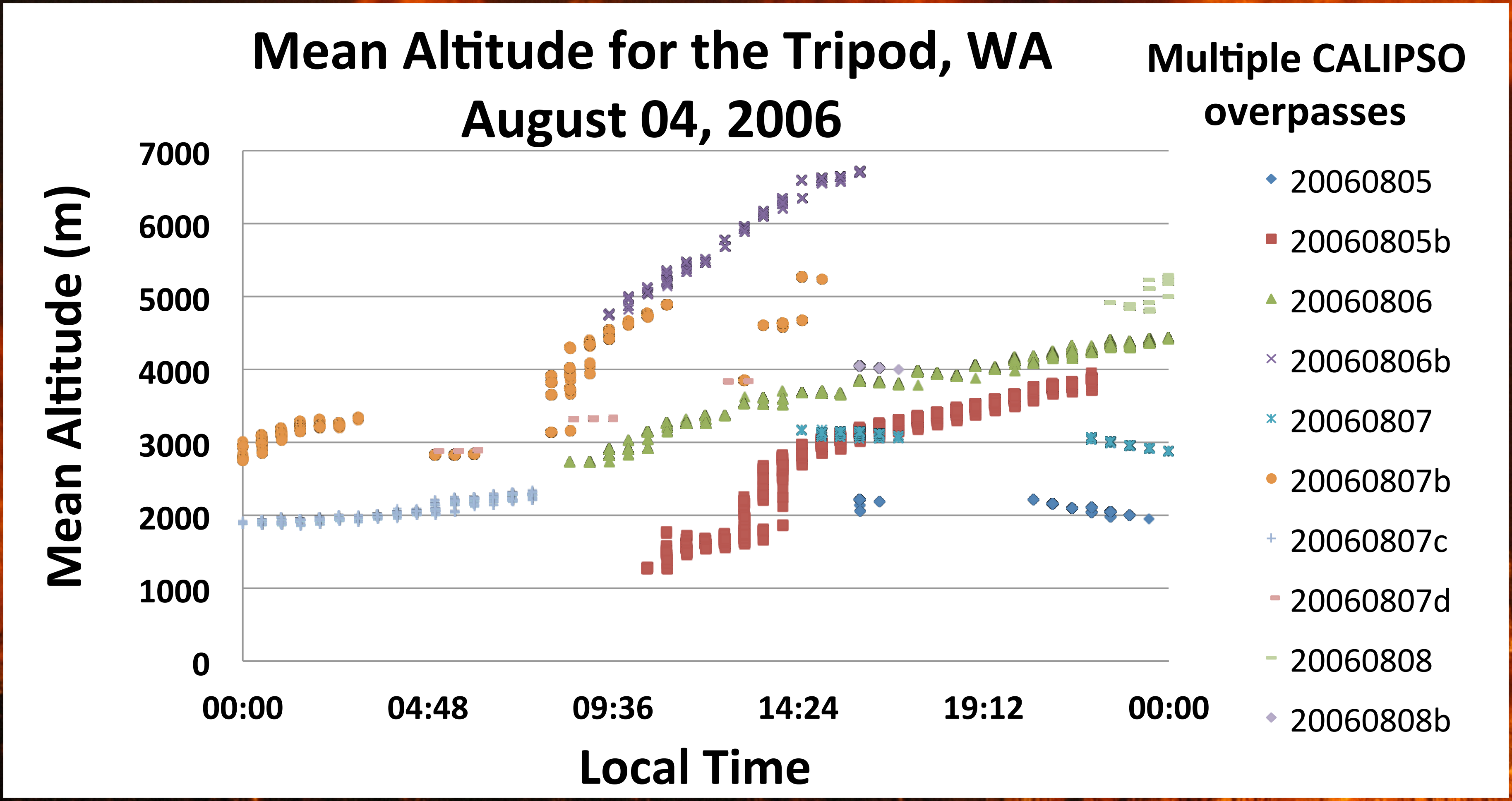
- August 6th – mean 1980 m

Saskatchewan (2 fires)

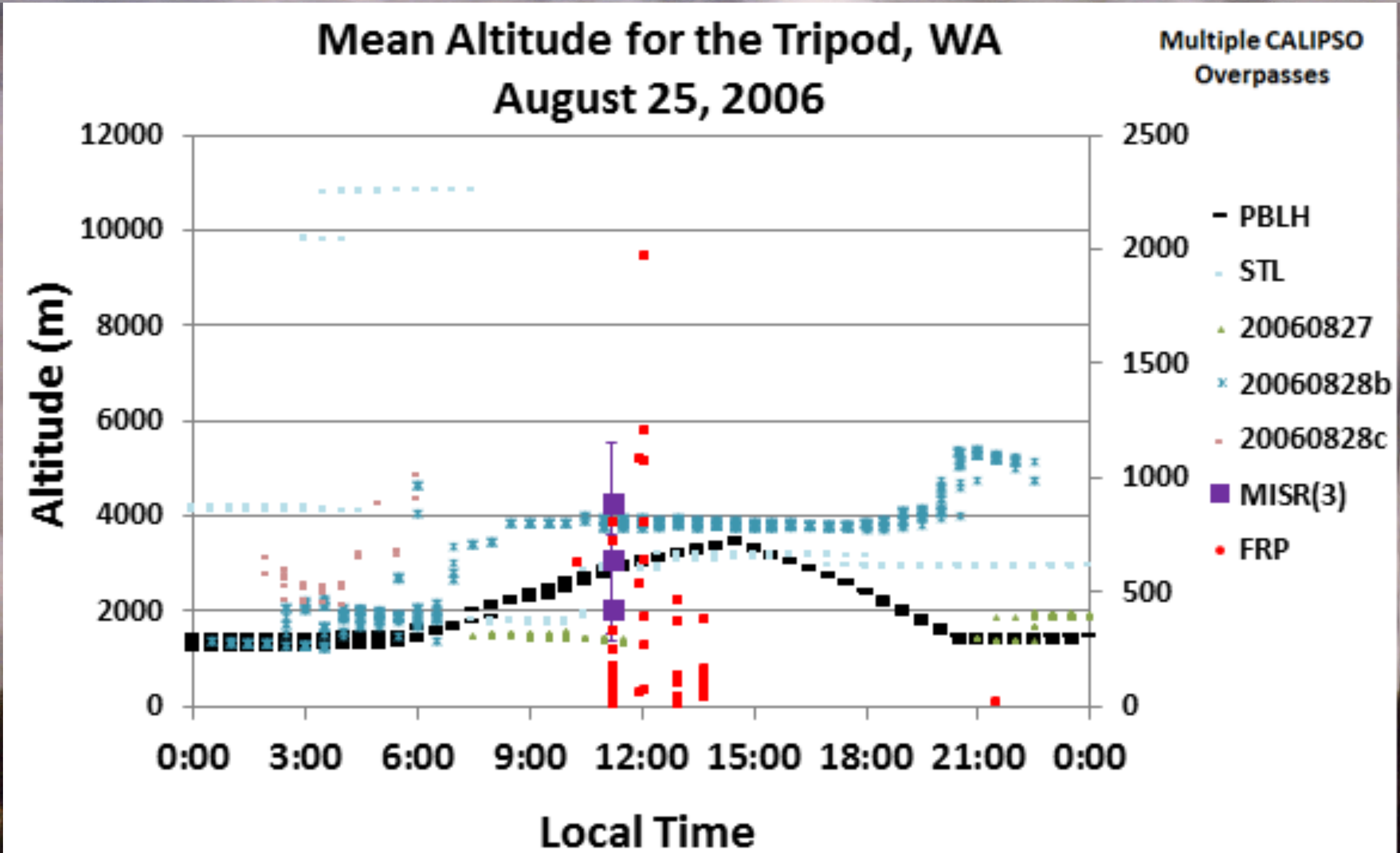
- August 6th and 7th ~ 1000 m

North Dakota (2 fires) August 7th ~ 2000 m

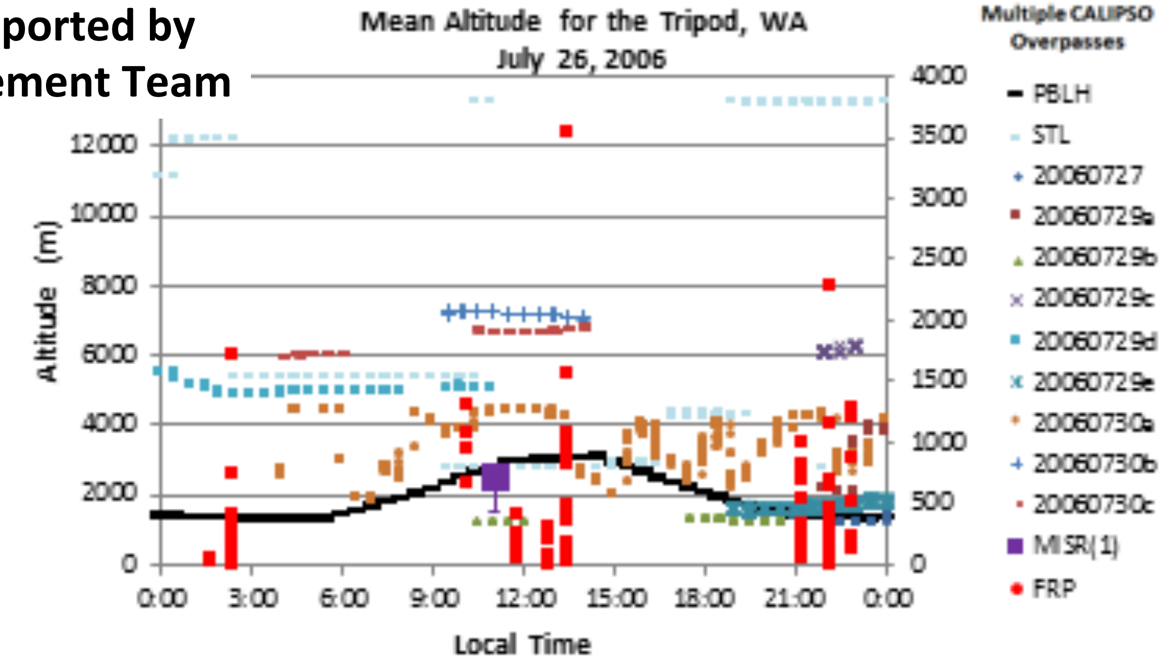
# Using multiple CALIPSO overpasses (w/ LaTM), the evolution of a smoke plume can be defined. This is unique and a new application.



# Mean Altitude of the Tripod Fire: CALIOP and MISR data compare well



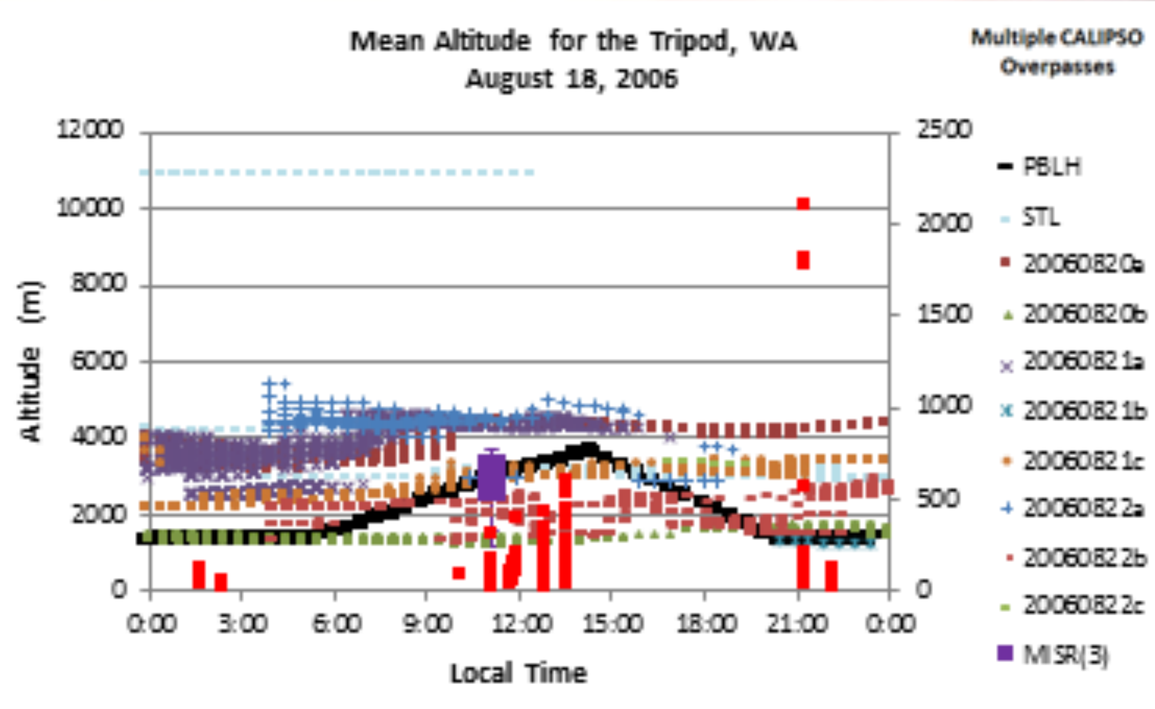
6700 – 7600 m reported by Incident Management Team



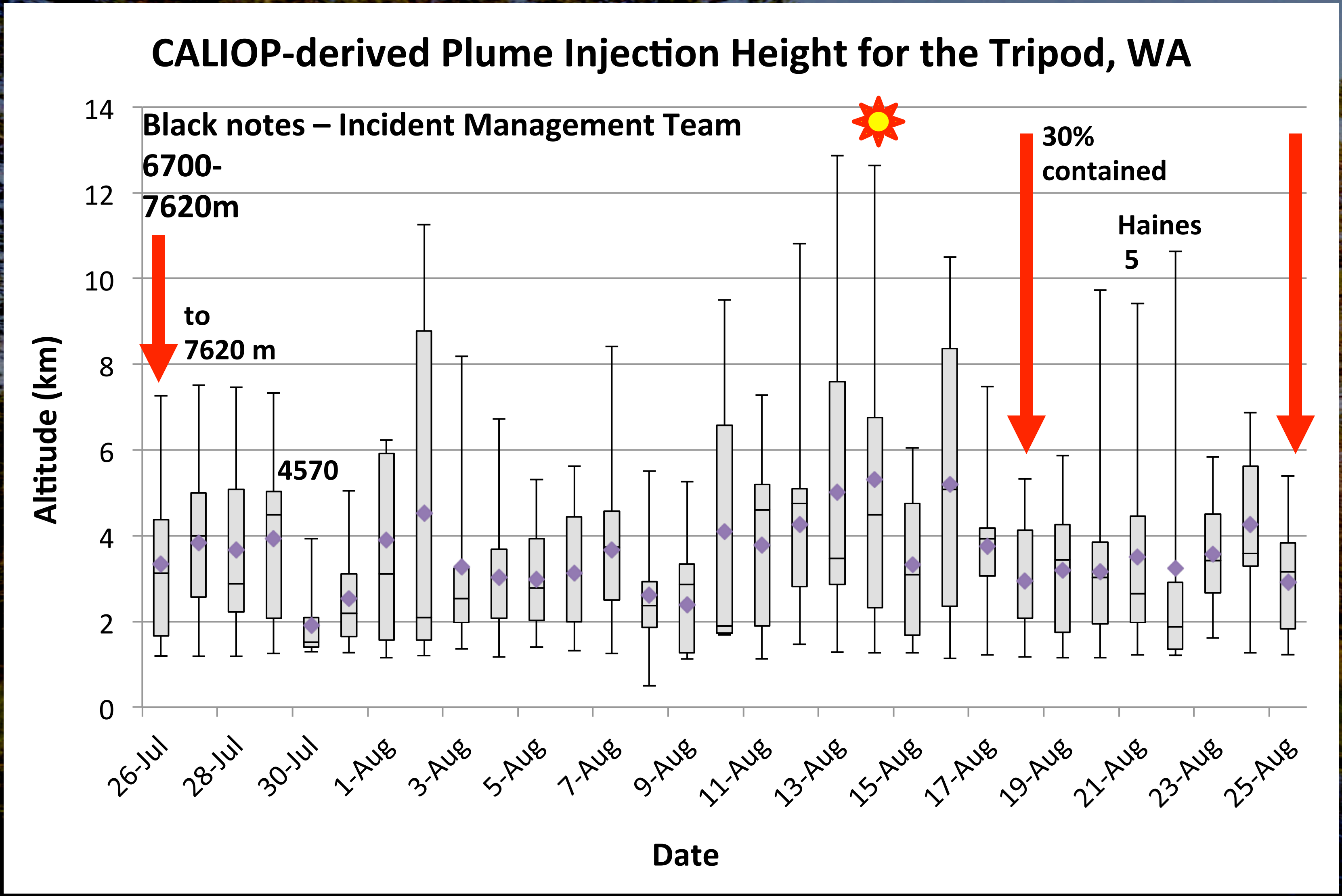

CALIOP data are used to define the daily smoke plume evolution of the Tripod Complex from July 26th through August 29th 2006.

MISR data capture morning overpasses for 3 days in this range.

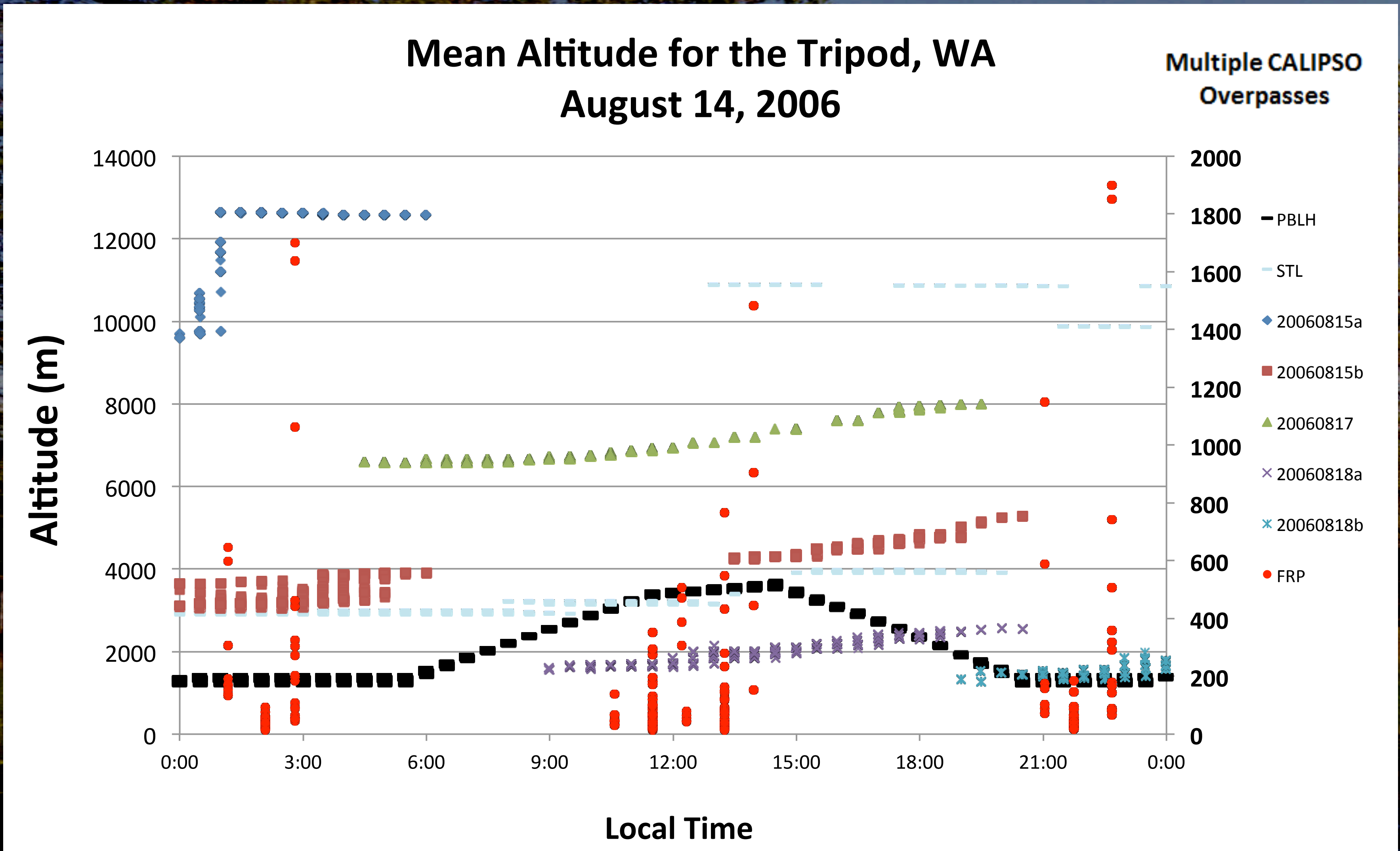
MISR low biased for all large plumes.



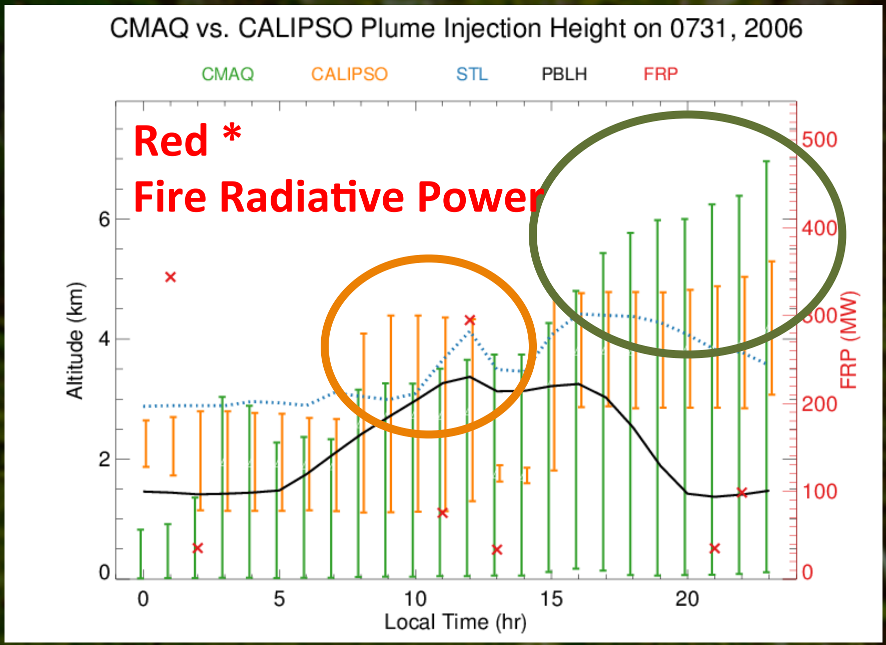
# Daily Smoke Plume Injection: Tripod Complex 2006
# Daily statistics (minimum, mean, median and maximum)
# Three coincident MISR days

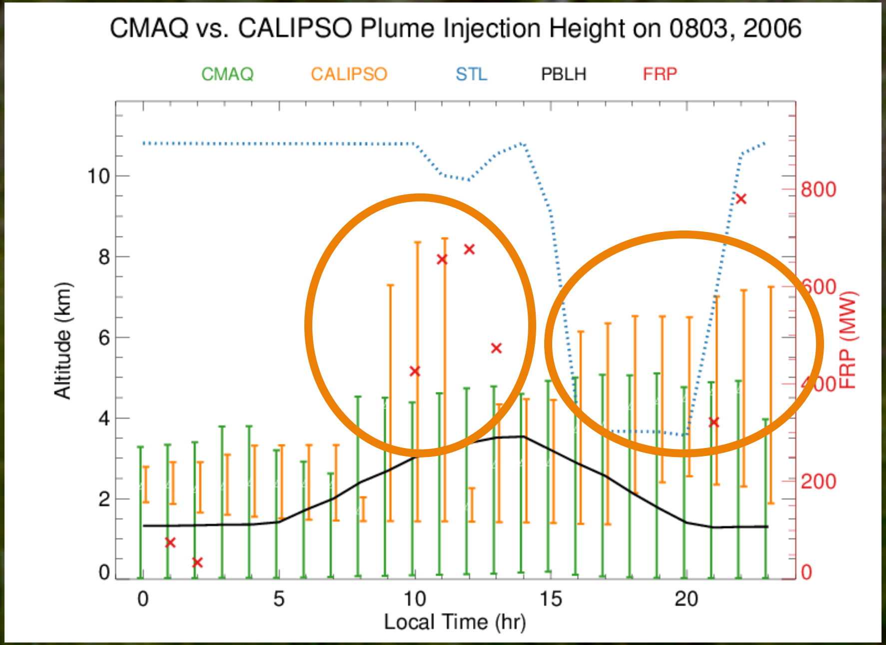


# High Fire Radiative Power and coincident smoke injection



# Comparing CALIOP and CMAQ modeled Injection Height

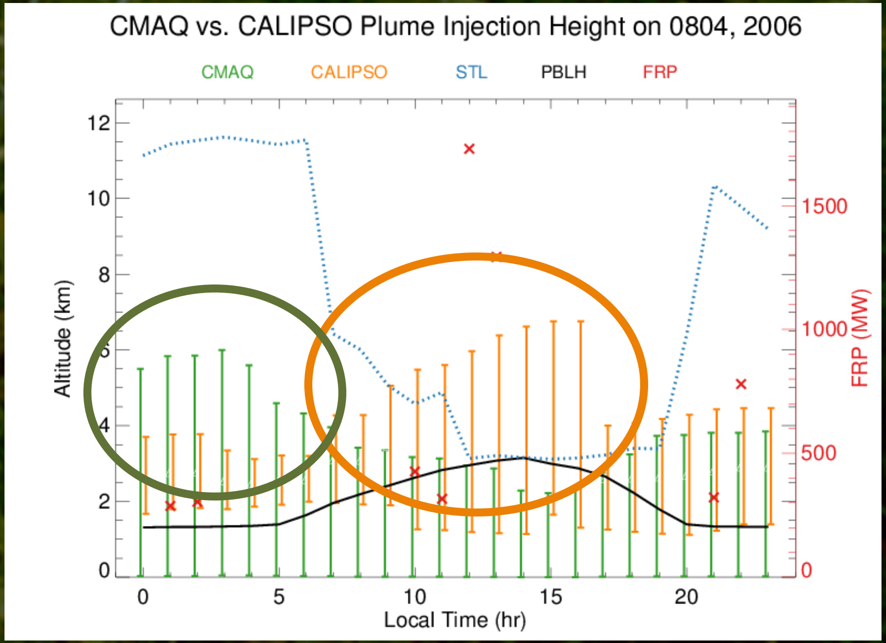



**Comparing CMAQ and CALIOP: Initial Analysis**

CMAQ tends to underestimate when the fires are burning the hottest (FRP) and;

CMAQ tends to overestimate late and early when the FRP is lowest.



## Concluding Thoughts:

- ❖ CALIPSO data provide a spatially & temporally random view of fire plume data, one not limited to particular fire types or times of day.
- ❖ One CALIOP swath can be representative of a complicated 3-D temporal and spatial story that incorporates several days, several fire events and a range of fire types from agricultural to large wildfires.
- ❖ CALIOP data can define the evolution of smoke over a day, which is a completely new process and result.
- ❖ CALIOP data have been used to tease apart scientific concepts about which we had not thought (e.g., Ice sheet aerosol distribution).
- ❖ CALIOP data can be used in many Application processes that define plume injection height for air quality, chemical transport and climate change feedbacks.
- ❖ In concert, CALIOP and MISR data will add to the statistical knowledge necessary to improve our understanding of the dynamics of fire plume injection height.

# Thank-you for listening!

and thanks for helpful conversations with individuals and communities: the CALIPSO Science Team, USDA Forest Service, Environmental Protection Agency, ARCTAS/ARCPAC science teams, LARGE Team, NOAA HMS team, Brian Stocks, Louis Giglio, Charles Ichoku, Ralph Kahn, Mark Ruminski and many others.

## Questions?

A special thanks to the NASA ASP program for seed funding under a DECISIONS project

**Using the LaTM, FD, samples taken from pits, and CALIOP data, we can tease apart feedbacks to climate. Specifically, preliminary analysis shows, it is not the amount of fire that burns that is directly related to deposition, rather a complicated pattern of fire, smoke transport, storms and snowfall.**